EXPERIMENTS WITH THE LOW MELTING INDIUM-BISMUTH ALLOY SYSTEM

Richard P. Krepski

Intermet Technology
116 Long Road
Georgetown, Pennsylvania 15043

Telephone 412-573-7754

EXPERIMENTS WITH THE LOW MELTING INDIUM-BISMUTH ALLOY SYSTEM*

Richard P. Krepski
Intermet Technology, Georgetown, PA
-and-
Geneva College, Beaver Falls, PA

KEY WORDS: indium-bismuth alloy, phase diagram, intermetallic compounds, oxidation, solidification, casting, heavy metal toxicity, wetting behavior

PREREQUISITE KNOWLEDGE: The primary audience for this material is the junior high school or middle school science student having no previous familiarity with the material, other than some knowledge of temperature and the concepts of atom, element, compounds, and chemical reactions. The unit can be adapted to use at a more advanced level, as a means of exploring the meaning of the equilibrium phase diagram.

OBJECTIVES: The alloy system indium-bismuth has several features that make it useful for participatory demonstrations at the pre-college level. Near the eutectic composition, the liquidus is well below the boiling point of water, allowing simple, minimal hazard casting experiments. Such phenomena as metal oxidation, formation of intermetallic compound crystals, and an unusual volume increase during solidification could all be directly observed. A key concept for students to absorb is that properties of an alloy (melting point, mechanical behavior) may not correlate with simple interpolation of properties of the pure components. Discussion of other low melting metals and alloys leads to consideration of environmental and toxicity issues, as well as providing some historical context. Wetting behavior can also be explored.

EQUIPMENT AND SUPPLIES: 1) Small pellets of pure indium and bismuth, along with 100 gram samples of pre-alloy with 34 and 60 wt.% Bi; 2) A hot plate or other modest heat source; 3) Temperature measurement capability in the range 50 - 160 $^{\circ}$C, preferably a thermocouple with digital readout; 4) Stainless steel cups; 5) Plastic spatula; 6) Glass Slide; 7) Plastic funnel; 8) Various clay media for mold making; 9) Eye protection for all students, and gloves for students involved with melting; 10) Mineral sample showing crystal facets.

PROCEDURE:

1. Have a volunteer inspect the sample of pure indium (very soft and ductile - can be dented by a fingernail). We will then

* Development of this experiment was supported by a grant provided by the National Science Foundation Small Business Innovation Research Program.

explore mechanical behavior of pure bismuth and the two alloys by knocking samples inside plastic bags on a table top. (First explain what is meant by weight percent and "alloy".) The 60 wt.% bismuth alloy is very brittle and shatters like glass; the 34 wt.% bismuth alloy is very tough and is unaffected. The pure bismuth is hard and brittle, but not to the extent of the bismuth-rich alloy.

> Caution: Pass these samples around inside plastic bags; small chips of fractured metal could otherwise get on students' fingers and get rubbed into eyes.

Lead the students in a guided discussion of the possible reasons for these differences in mechanical behavior. Point out that the 60 wt. % bismuth alloy shows very flat surfaces where it breaks. This is a reflection of the crystal structure of the material - the way the atoms line up in orderly patterns when the metal solidifies. This alloy is mostly an extremely brittle InBi compound, and its fracture surface displays the planes of these crystals. Compare this to a highly "faceted" crystalline mineral like amethyst of fluorite. The other alloy is tough (difficult to crack) because it is a fine combination of two kinds of crystals - indium (with dissolved bismuth) and the fairly tough In_2Bi cmpound. Which alloy would the students choose to make a part from?

2. Introduce the periodic table and look up the crystal structures of indium and bismuth - no need to get into detail unless the kids ask. Also look up melting points. Bismuth melts at 271°C, Indium at 157°C...what temperature do they think the alloys will melt at? A logical guess would be to plot melting temperature versus composition and just draw a straight line between the two endpoints.

Melt the 60 wt. % bismuth alloy chunk in a stainless cup on a hotplate and measure temperature with thermocouple. It should go liquid at about 105°C. Why is melting point lower than for either pure material? Basically, the two different atoms have a hard time fitting together into a solid crystal structure.

> Caution: Do not let the metal temperature get too much above 120°C, as this increases the burn hazard. All students should have protective eyewear. Students handling temperature measurement should wear gloves.

<u>While waiting for alloy to melt:</u> We have been using the word "metal". What are some metals in the room, and what makes a metal a metal? Students might say strength, or ability to bend like a wire, or shininess. Point out an electric wire and ask if there is metal in it and what it does. As another clue, discuss how a thermocouple measures temperature. When two different metal wires are joined together to make a circuit and the two junctions are at different temperatures, electrons will flow from one metal to the other - we can measure this effect, the magnitude of which depends on the temperature difference between the two junctions. This reinforces the notion of electrons freely flowing in a metal,

because of the way the atoms are bonded together. This is really what makes a metal a metal.

Students should be able to make five key observations as we melt and re-solidify the metal in the stainless steel cup:

A. Cool the cup by immersing it in water...we should be able to see the expansion in the solid as it forms on the outside of the cup. This is very unusual, and is due to the very open crystal structure. What other common material becomes less dense (expands) when it solidifies?? Have a glass of icewater available, to show solid ice floating in liquid water. What would happen if ice was more dense than water? Ice in lakes and oceans would sink to the bottom and take a much longer time to melt in the spring - something to think about!

B. On cooling, we will be able to see the higher melting crystals (InBi) forming first in the middle of the sample. When the alloy is partially solid, tip the cup to shift the liquid and expose the solid crystals.

C. We should also note that the alloy is slushy over a range of temperatures - it doesn't just freeze at a single temperature like water or pure indium or bismuth. This is typical of many alloys.

D. When the alloy is molten we should be able to see an oxide skin forming on the melt surface as it reacts with the air...discuss how nature would like to convert this metal into an oxide, and how melting allows this to happen faster. Note also that a protective chromium oxide steel on the stainless steel cup is actually what makes it "stainless". The oxide film is so thin that we can't see it. If the steel surface is scratched, chromium from the steel quickly reacts with the air to "heal" the protective film.

E. Using the glass slide, we can demonstrate that the liquid metal wets glass. This is unusual and relates to one practical use for indium-containing alloys - soldering of nonmetals.

3. Second melting experiment with 34 wt. % bismuth: Repeat the procedure above. In this case, the alloy melts and resolidifies at a temperature of about 72^{o}C. This is the lowest melting composition. Note also that there is little or no range of slushiness - the alloy changes from solid to liquid and back again at constant temperature. Go back to our map of melting point versus composition and plot the data we have generated for the two alloys. Is this what we expected?

4. The fact that the 34 wt. % bismuth alloy melts below the boiling point of water enables us to perform some simple casting experiments - we don't have to worry about boiling water when we cast into a wet medium like clay, and the low melting point in

general reduces the hazard from molten metal. Still, students and teachers need to have a healthy respect for the hot alloy, and wear eye and hand protection. To eliminate the risk of overheating the metal, it might be suitable to switch to a double boiler configuration with the stainless steel cup sitting in a larger vessel of boiling water.

This is a "guided discovery" section of the experiment, in which students should decide what approaches to take. Among the issues that should be addressed are:

A. What pattern can be used for the casting? A student's fingertip works well - the fingerprint can be precisely replicated because the alloy expands as it solidifies.

B. What mold material works best and why? PlayDoh® or its equivalent forms nicely and does not soften or melt when in contact with the molten metal.

C. What is the effect of casting metal temperature on casting quality?

D. How can we avoid trapping air and the oxide that floats on top of the molten metal? The funnel can be used as a means of feeding the melt into the mold.

Students would probably like to keep these castings. However, the cost of indium is on the order of $200/lb! There are low melting alloys that are very inexpensive, but these contain toxic heavy metals like lead and cadmium.

<u>INSTRUCTOR NOTES</u>: This experiment is part of a more extensive program dealing with low melting point metals. It is important to start the presentation with something physical that grabs the students' attention. In this case, an encapsulated mercury globule is passed around. This is an object of fascination, and one that not too many young students have seen because of mercury's environmental problems. The simple mercury toy provides a possible basis for discussion of surface tension and wetting behavior, past and present uses, and toxicity problems. After the casting experiment, we pursue a similar theme talking about lead. One interesting approach is to state that every student has passed within a few feet of several pounds of lead that day - can they guess where it was? Surprisingly, even college students can't identify the lead-acid car battery without a number of hints. Besides toxicity, another theme that links these materials together is wetting behavior and soldering. Mercury doesn't wet glass; lead alloy solders wet copper, but only in conjunction with a flux; indium alloys wet just about anything.

Note that this write-up contains a good deal of information that may not be used in a given presentation. It is important to go in the direction that student input leads, and to be flexible. Structuring the presentation as a lecture, especially at the

beginning, will trigger a glazed-over expression on most faces. If that happens, quickly shift to something more hands-on and interactive.

The indium-bismuth experiment can be adapted for use at more advanced levels. In the college classroom, it can be used to reinforce the concept of phase diagrams. Crystal structure diagrams or models and actual microstructures with microhardness indents can be used. For senior high school students, a challenging follow-up exercise would be to start with the measured weight percent compositions of the two intermediate compounds in the Indium-Bismuth system (64 and 48 weight % bismuth), and develop the calculation to convert to atomic percents. We find the two compositions are exactly 50 at.%Bi and 33.3 at.%Bi, corresponding to InBi and In_2Bi and suggesting that the two compounds form fairly simple structures. This calculation requires concepts of atomic weight and Avogadro's number. To appreciate magnitudes, we can calculate the "gram-atomic weight" of 22 pound (10 Kg) bowling balls. If each bowling ball was an atom, a gram-atom of each would weigh the same as planet Earth - 6×10^{27} grams. In comparison, the weight of the same number of carbon atoms is 12 grams! To promote student reading and considerations of ethics, have older students read Kurt Vonnegut's Cat's Cradle, in which a scientist develops a new crystal form of ice that melts at high temperature, with disastrous consequences! This is a nightmarish example of a scientist out of touch with the world and his professional responsibilities. Follow up with a class discussion of these issues.

This experiment is also being adapted for in-service training of teachers, who are provided experimental materials to use in their classes. Because of alloy cost, the unit is abridged to use only enough indium alloy to cast one student finger at a time. Melting is accomplished by the double-boiler approach to avoid the risk of overheating metal.

Details of this full program and other materials science modules developed by Intermet Technology are provided in the project report to the National Science Foundation Small Business Innovation Research program.

SOURCES OF SUPPLIES: Indium alloys were obtained from Indium Corp. of America. They are very expensive! A digital thermocouple is nice but not necessary - ours was obtained from Marlin Manufacturing in Pittsburgh for $120. Intermet Technology eventually plans to put together experimental packages and support literature for use in both teacher in-service and "scientist in the classroom" programs.